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National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Region
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Seattle, WA 98115

NMFS Tracking No: 2010/04306

January 31, 2011

Jannine Jennings
Water Quality Standards Unit Manager
Office of Water and Watersheds
U.S. Environmental Protection Agency
1200 Sixth Ave.
Seattle, Washington 98101

RE: Endangered Species Act Section 7 Informal Consultation and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the proposed approval of Idaho's Water Quality Criteria for Cadmium (One project)

Dear Ms. Jennings:

This responds to your letter of September 2, 2010, which requested Endangered Species Act (ESA) consultation and Magnuson-Stevens Fishery Conservation and Management Act (MSA) consultation on the subject action. You described the potential impacts on Snake River spring/summer Chinook salmon, Snake River fall Chinook salmon, Snake River sockeye salmon, Snake River Basin steelhead, designated critical habitat, and Essential Fish Habitat (EFH) under National Marine Fisheries Service (NMFS) review. Your letter and accompanying biological evaluation (BE) described a change in water quality criteria for cadmium, and requested concurrence with your determination that the criteria proposed for approval was protective of and not likely to adversely affect Snake River salmon and steelhead. The project has been reviewed by NMFS, as provided under section 7(a)(2) of the ESA and its implementing regulations, 50 CFR part 402, and section 305(b)(2) of the MSA and its implementing regulations, 50 CFR Part 600.

We did not rely solely on the analyses in the BE to make our determination, but rather conducted our own review, as described below. This was done because the BE evaluated potential adverse effects to listed species using fundamentally different concepts than those that NMFS uses. In the BE, the tests for whether effects were insignificant were made at the level of a population of listed species. In contrast, the threshold for insignificant effects used by NMFS is that "take" should never occur. Tests for "take" are usually interpreted as harm to individuals of a listed species, not as requiring harm to up to 50% of a population of a listed species.

Thus, NMFS independently reviewed the data on the effects of cadmium to listed species and their ecosystems in some detail. Attached is a technical memorandum summarizing this review, "*An* *evaluation of the protectiveness of ambient water quality criteria for cadmium for Snake River anadromous salmon and steelhead.*" We believe this review, and the references cited therein, reflect the best scientific data available for the potential effects of cadmium on listed Snake River salmon and steelhead and their critical habitats.

Endangered Species Act

Snake River spring/summer Chinook salmon, Snake River fall Chinook salmon, Snake River sockeye salmon, and Snake River Basin steelhead occur within the statewide action area. The action would apply to designated critical habitat for ESA listed Snake River spring/summer Chinook salmon, Snake River fall Chinook salmon, Snake River sockeye salmon, and Snake River Basin steelhead (Table 1). Pursuant to NMFS' ESA responsibilities and authorities, NMFS evaluated the effect of the project on ESA listed species and designated critical habitat.

Table 1. Federal Register notices for final rules that list threatened and endangered species, designated critical habitat, or apply protective regulations to listed species considered in this consultation. (Listing status: 'T' means listed as threatened under the ESA; 'E' means listed as endangered.

Species	Listing Status	Critical Habitat	Protective Regulations
Chinook salmon (*Oncorhynchus tshawytscha*)			
Snake River spring/summer run	T 6/28/05; 70 FR 37160	10/25/99; 64 FR 57399	6/28/05; 70 FR 37160
Snake River fall-run	T 6/28/05; 70 FR 37160	12/28/93; 58 FR 68543	6/28/05; 70 FR 37160
Sockeye salmon (*O. nerka*)			
Snake River	E 6/28/05; 70 FR 37160	12/28/93; 58 FR 68543	ESA Section 9 applies
Steelhead (*O. mykiss*)			
Snake River Basin	T 1/05/06; 71 FR 834	9/02/05; 70 FR 52630	6/28/05; 70 FR 37160

Species Determination

The EPA is proposing to approve the State of Idaho's revised water quality criteria for cadmium to protect aquatic life. Criteria are proposed for chronic exposure at 1.3 micrograms per liter and acute exposure at .6 micrograms per liter. These values are for water with a hardness of 100 milligrams per liter. The criteria values vary according to the hardness of the water based on an identified formula.

The proposed criterion maximum concentration, also referred to as the acute criterion for cadmium is unlikely to adversely affect Snake River spring/summer Chinook salmon, Snake River fall Chinook salmon, or Snake River sockeye salmon. This is the case because all reports reviewed of concentrations causing acute effects to Chinook salmon or to sockeye salmon were higher than the comparable criteria statistics. However, a substantial percentage (about 23%) of the available acute data most relevant to Snake River steelhead did indicate adverse effects were likely. This percentage is too high to never reach the scale where take occurs, which is a test for "insignificant" effects. Therefore, estimates of the efficacy of three of USEPA's proposed "conservative measures" which related to effluent and receiving water flow volume assumptions were made. The estimates were that for about 90% or more of the time, the compounded conservatism resulting from three flow-related assumptions was about a factor of 0.5 or less (i.e., would be about twice as protective as the "face value" criteria concentrations). As implemented with "conservative measures", the resulting cadmium concentrations would be lower than the great majority of data reviewed on adverse effects of cadmium.

For these reasons, the cadmium criteria that are proposed for approval for Idaho would be likely to only have insignificant effects on listed Snake River anadromous salmonids or their designated critical habitats.

Thus, based on the best available information reviewed in the attached technical memorandum and consistent implementation of the "conservative measures" described in the BE, NMFS has determined the subject action would have only insignificant effects on the listed species. NMFS therefore concurs with the USEPA finding that the subject action is "not likely to adversely affect" listed Snake River spring/summer Chinook salmon, Snake River fall Chinook salmon, Snake River sockeye salmon, or Snake River Basin steelhead. If the conservative measures are not implemented consistent with USEPA's proposed action as described in the BE and analyzed in the technical memorandum, our determination may no longer be valid, and reinitiation may be required.

Critical Habitat Determination

NMFS reviewed the status of designated critical habitat affected by the proposed action by examining the condition and trends of primary constituent elements (PCEs) throughout the designated area. The PCEs consist of the physical and biological features identified as essential to the conservation of the listed species (Table 2). The relevant PCE for this action is water quality. The proposed action would replace existing cadmium criteria, that were based on the best science available in 1984, with more stringent criteria (i.e., would result in lower allowable effluent concentrations and lower allowable instream concentrations) that were based on more recent science. In particular, the proposed criteria are considerably more protective in very soft waters that sometimes occur in the action area. For example, at a water hardness of 10 milligrams per liter (mg/L), the proposed cadmium criterion for indefinite exposures is 0.14 micrograms per liter (µg/L). In contrast, the existing comparable criterion value is 0.37 µg/L.

NMFS also considered how climate change predictions would alter the effects of the proposed action. In Idaho, climate change models predict that low stream flows will further decline; however, these changes will be measurable at the time scale of decades. The cadmium criteria will be primarily used in the issuance of National Pollution Discharge Elimination System (NPDES) permits for waste water discharges that are subject to a 5-year term. The discharge levels in the permits are based on calculated low flows for the previous 10 year period and these considerations will prevent possible changes in flow conditions related to climate change from exceeding those that were analyzed in this concurrence letter.

Table 2. Types of sites and essential physical and biological features designated as PCEs, and the species life stage each PCE supports.

Site	Essential Physical and Biological Features	ESA-listed Species Life Stage
Snake River Basin Steelhead[a]		
Freshwater spawning	Water quality, water quantity, and substrate	Spawning, incubation, and larval development
Freshwater rearing	Water quantity & floodplain connectivity to form and maintain physical habitat conditions	Juvenile growth and mobility
	Water quality and forage[b]	Juvenile development
	Natural cover[c]	Juvenile mobility and survival
Freshwater migration	Free of artificial obstructions, water quality and quantity, and natural cover[c]	Juvenile and adult mobility and survival
Snake River Spring/summer and Fall Chinook Salmon		
Spawning and Juvenile Rearing	Spawning gravel, water quality and quantity, cover/shelter, food, riparian vegetation, and space	Juvenile and adult.
Migration	Substrate, water quality and quantity, water temperature, water velocity, cover/shelter, food[d], riparian vegetation, space, safe passage	Juvenile and adult.
Snake River Sockeye Salmon		
Spawning and Juvenile Rearing	Spawning gravel, water quality and quantity, water temperature, food, riparian vegetation, and access	Juvenile and adult.
Migration	Substrate, water quality and quantity, water temperature, water velocity, cover/shelter, food[d], riparian vegetation, space, safe passage	Juvenile and adult.

a. Additional PCEs pertaining to estuarine, nearshore, and offshore marine areas have also been described for Snake River Basin steelhead. These PCEs will not be affected by the proposed action and have therefore not been described in this letter of concurrence.
b. Forage includes aquatic invertebrate and fish species that support growth and maturation.
c. Natural cover includes shade, large wood, log jams, beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks.
d. Food applies to juvenile migration only.

Based upon the information considered in the attached review, NMFS concurs with the USEPA finding that the subject action is "not likely to adversely affect" designated critical habitat for Snake River spring/summer Chinook salmon, Snake River fall Chinook salmon, Snake River sockeye salmon, and Snake River Basin steelhead.

Magnuson-Stevens Fishery Conservation and Management Act

Federal agencies are required, under 305(b)(2) of the MSA and its implementing regulations (50 CFR 600 Subpart K), to consult with NMFS regarding actions that are authorized, funded, or undertaken by that agency that may adversely affect EFH. The MSA defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." If an action would adversely affect EFH, NMFS is required to provide the Federal action agency with EFH conservation recommendations (MSA 305(b)(4)(A)). This consultation is based, in part, on information provided by the Federal action agency and descriptions of EFH for Pacific salmon contained in Appendix A to Amendment 14 to the Pacific Coast Salmon Plan (August 1999) developed by the Pacific Fishery Management Council and approved by the Secretary of Commerce (September 27, 2000).

The proposed action and action area are described in the BE. The action area includes habitat which has been designated as EFH for various life stages of Chinook and coho salmon. Because the habitat requirements (i.e., EFH) for Chinook and coho salmon in the action area are similar to those of the ESA-listed species and because the conservation measures included as part of the proposed action are adequate to address ESA concerns, they are also adequate to avoid, minimize, or otherwise offset potential adverse effects to designated EFH. Therefore, conservation recommendations pursuant to MSA (305(b)(4)(A)) are not necessary.

This concludes informal ESA consultation on this action in accordance with 50 CFR 402.14 (b)(1), and MSA consultation in accordance with 50 CFR 600.920 (e)(3). The USEPA must reinitiate consultation on this action if new information becomes available, or if circumstances occur that may affect listed species, designated critical habitat, or EFH in a manner, or to an extent, not previously considered. This letter of concurrence meets the applicable Information Quality Act standards for utility, integrity, and objectivity. This review was primarily conducted by Mr. Chris Mebane who was advised by Dr. Scott Hecht and Dr. Jim Meador. For questions, please contact David Mabe at 208/378-5698.

Sincerely,

William W. Stelle, Jr.
Regional Administrator

Attachment

cc: Brian Kelly – USFWS
C. Mebane – c/o ISHO

An evaluation of the protectiveness of proposed water quality criteria for cadmium for Snake River anadromous salmon and steelhead.

FIGURES

TABLES

ACRONYMS

7Q10	7-day, once in 10 year low flow
BAF	bioaccumulation factors
BCF	Bioconcentration factors
BE	Biological Evaluation
CCC	Chronic criterion concentration
DOD	Dissolved Organic Carbon
ESA	Endangered Species Act
FAV	Final Acute Value
GMAV	genus mean acute values
LOEC	Lowest Observed Adverse Effect Concentration
NMFS	National Marine Fisheries Service
NOEC	No Observed Adverse Effect Concentrations
NPDES	National Pollution Discharge Elimination System
NTR	National Toxics Rule
SMAV	species mean acute value
TCM	Thompson Creek Mine
TSC	toxic screening concentration
USEPA	U.S. Environmental Protection Agency
WET	Whole-Effluent Toxicity

1. BACKGROUND

The U.S. Environmental Protection Agency (USEPA) is proposing to approve changes to Idaho's water quality standards for cadmium. The potential effects of the action to species listed under the Endangered Species Act (ESA) and their critical habitats were evaluated in an analysis titled "*Biological evaluation of the Idaho water quality criteria for cadmium with revised hardness cap*" (BE)(*USEPA 2010*). There, USEPA concluded that the effects of the action were not likely to adversely affect any listed species.

However, National Marine Fisheries Service (NMFS) could not rely exclusively on USEPA's (*2010*) analysis and determination because USEPA (*2010*) evaluated the likelihood and magnitude of potential adverse effects to listed species using fundamentally different concepts from those that are typically used by NMFS. "Take" is defined under the ESA as any harm to individuals of a listed species, not as harm to up to 50% of a population of a listed species. Population-level analyses are very relevant to evaluating whether the projected take of individuals would likely jeopardize the survival or recovery of listed species by reducing the reproduction, numbers or distribution of that species (*USFWS and NMFS 1998*). Thus in lieu of being able to rely on the subject BE to determine whether NMFS would reach the same determination as did USEPA that the subject action was unlikely to adversely affect listed species or critical habitats, it was necessary for NMFS to also independently review the data on the effects of cadmium to listed species and their ecosystems as follows. In our review, we were informed by data presented or referenced in the BE and considered USEPA interpretations.

1.1. Judgments on the likelihood of adverse effects need to be made for individuals rather than entire populations of listed species.

The need to conduct an independent review with special attention to "conservative measures" was in large part because of differing views over how the protectiveness of the cadmium criteria was interpreted. In ESA section 7 consultations, it is appropriate to reach a conclusion that an action "is not likely to adversely affect" listed species if the effects of the action are "insignificant" or "discountable." Insignificance is related to the magnitude of effects, and effects that are insignificant "*relate to the size of the impact and should never reach the scale where take occurs*" (*USFWS and NMFS 1998*). Discountability is related to the likelihood of adverse effects, and the test is that discountable effects would be "*extremely unlikely to occur*" (*USFWS and NMFS 1998*).

For the evaluation of the acute cadmium criterion, the BE evaluated whether the potential effects of the criterion were insignificant by: (1) Searching USEPA's EcoTox database for LC50 values for species of interest such as Chinook salmon or rainbow trout (the LC50 is the concentration estimated to kill 50% of the organisms in a test); (2) downloading the search results and taking the geometric mean of the various test LC50s to calculate a "species mean acute value" or SMAV; and (3) dividing the SMAV by 2 to extrapolate from a concentration that on the average is severely toxic (i.e., kills half the fish) to a concentration that on the average is expected to kill few fish. The BE considers the SMAV/2 value to be the benchmark for comparing with the cadmium criterion to determine if effects are "insignificant":

> *"Once USEPA estimated the concentration of ... [cadmium] that is not likely to significantly impact the population of the species in an aquatic ecosystem, and therefore, will not result in a significant impact on the threatened and endangered species in Idaho, USEPA then compared these SMAV/2 values to the Idaho cadmium criteria."* (BE at section 4.1.2)

In other words, in the BE the test for whether effects are insignificant was based on effects to an entire population of the listed species. In contrast, in the Consultation Handbook, the threshold for insignificant effects is that "take" should never occur. Tests for "take" are usually interpreted as harm to members of a listed species, not as requiring harm to up to 50% of a population of a listed species.

These different approaches to considering thresholds of "insignificance" could lead to drawing different conclusions from reviews of similar data. The case in point is rainbow/steelhead trout. In the acute criterion dataset, the rainbow trout SMAV of 2.0 µg/L Cd is greater than the Final Acute Value of 1.5 µg/L used to set the criterion. Yet 8 of 35 or 22% of the rainbow trout LC50s are lower than the Final Acute Value. Treating these 35 rainbow trout values as a population in the statistical sense, we could not concur that effects projected to affect 22% of a population were "insignificant" or "discountable."

If for a population of data in this context, allowable effects of up to 50% of the population (i.e., the SMAV) are too high to be considered "insignificant," then instead of using the 50^{th} percentile, what percentile of effect could be recommended as more appropriate for testing for "insignificant" effects? The Consultation Handbook, advises that "*based on best judgment, a person would not: (1) be able to meaningfully measure, detect, or evaluate insignificant effects*." In the context of a statistic to describe a population of effect data, this advice would lead toward a very low threshold at or below the lowest test value for a species. Selecting a minimum value would probably be the only choice available for species with only a few data points, such as Chinook or sockeye salmon for example. However, for larger datasets such as rainbow/steelhead trout and cadmium, many ecotoxicologists would probably balk at relying solely only the lowest value which could be an outlier or suspect, to the exclusion of the body of data. These two conflicting considerations might lead to a compromise statistic where a low, non-zero percentile such as the 5^{th} or 10^{th} percentile of the population of effects data could reasonably fit the "insignificance" definitions and avoid the vagaries of extreme, low values.

Population-level analyses of effect are relevant to jeopardy analyses conducted as part of ESA section 7 consultations. Actions cannot "jeopardize the continued existence of" listed species and implementing regulations define "*jeopardize the continued existence of*" to mean "*to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers or distribution of that species*" (*USFWS and NMFS 2004)*. This definition requires some analysis or judgment of possibility of effects at the species level which in turn requires consideration of effects at the population level. But analyses on the lack of effect at the population level cannot be used by action agencies for screening out "likely to adversely affect" determinations at the biological assessment stage of consultations.

1.2. The existing and proposed-for-approval cadmium criteria

Both the cadmium criteria previously approved by USEPA for use in Idaho and the cadmium criteria proposed as the subject action vary as a function of the hardness of the water. The previously approved and proposed criteria are compared in Table 1. The comparisons shows that the proposed criteria would consistently be lower (i.e., more protective) than the previously USEPA-approved criteria. The chronic criterion that is intended to be protective for indefinite exposures is a little less than twice as low as the comparable existing criterion, and the acute criterion that is intended to protect against higher, short-term exposures is between 3 to 4 times as protective.

Table 1. Comparison of the cadmium criteria proposed for USEPA approval and the previously approved Idaho cadmium criteria for a range of hardness values expected within the range of listed salmon and steelhead in Idaho

Water hardness (mg/L as $CaCO_3$)	Previously approved criterion for short-term exposures (µg/L)	Proposed criterion for short-term exposures (µg/L)	Previously approved criterion for indefinite exposures (µg/L)	Proposed criterion for indefinite exposures (µg/L)
10	0.82	0.20	0.37	0.14
25	0.82	0.42	0.37	0.24
50	1.75	0.75	0.62	0.37
100	3.70	1.34	1.03	0.55
200	7.84	2.40	1.72	0.82

2. CADMIUM OCCURRENCE AND COMMON EFFECTS TO AQUATIC ORGANISMS

Cadmium is naturally rare in aquatic environments, which is fortunate since it is one of the most toxic of all natural substances to fish and other organisms (*Sorensen 1991*). In toxicity tests of all 63 atomically stable metals in the periodic table, cadmium was the most toxic to the benthic invertebrate *Hyalella azteca (Borgmann et al. 2005)*. Cadmium has a variety of industrial uses including electroplating, pigments, plastic stabilizers, batteries, and electronic components (*Sorensen 1991*). However, within the range of anadromous fish in Idaho, potential risks of elevated cadmium in aquatic environments are probably exclusively associated with disturbances from large-scale mining (Figure 1).

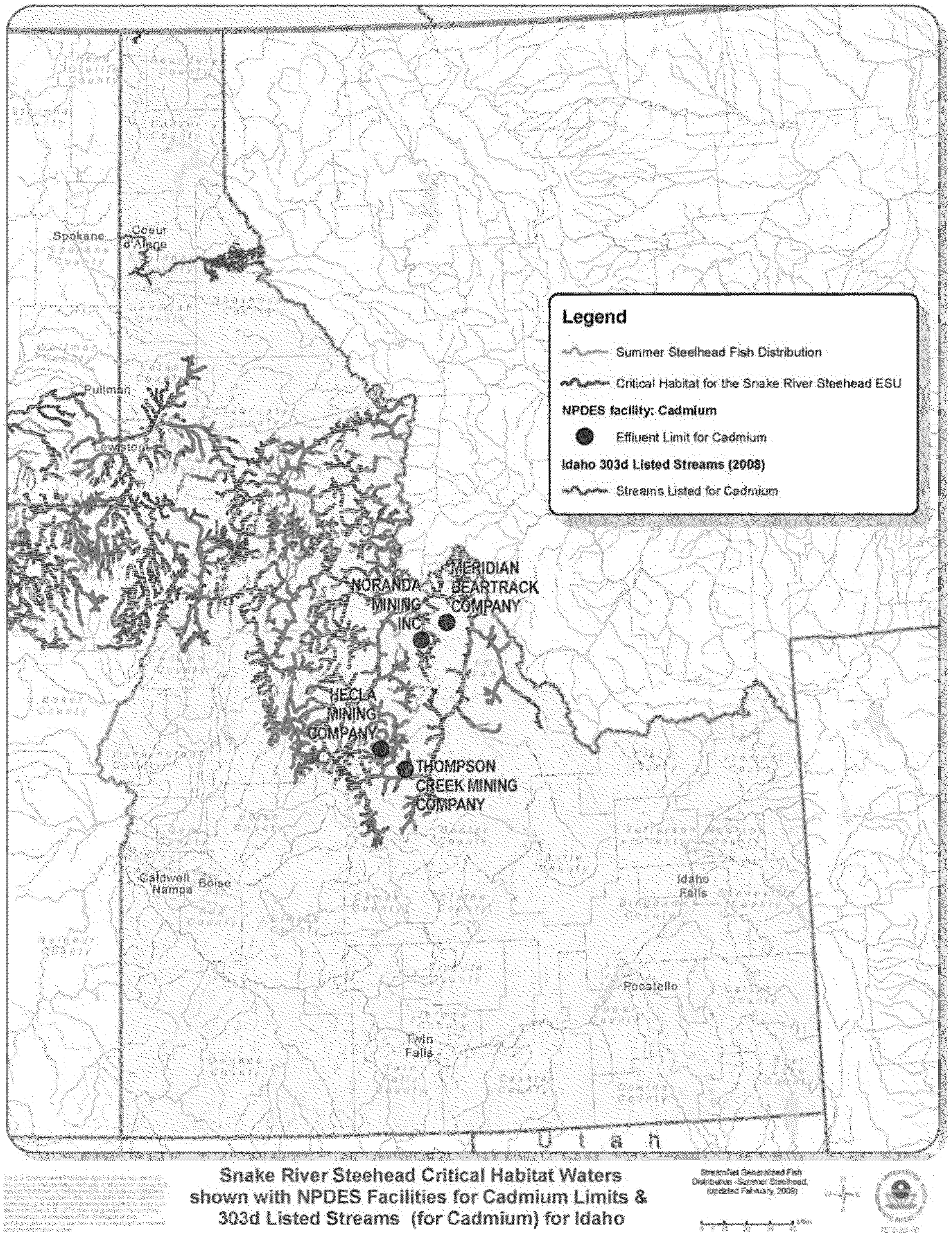


Figure 1. Overlay of locations with known cadmium risks to aquatic life and the distribution of anadromous fish in Idaho. Figure from USEPA (2010)

Adverse effects of cadmium at environmentally relevant concentrations include blood plasma and other hematological changes, decreased growth, inhibited reproduction, decreased immune response, loss of ability of prey to escape predators, loss of ability of predators to capture prey, and death. Salmonids are particularly sensitive to cadmium compared to most other fish species (*Sorensen 1991*; *Mebane 2006*). Toxicity of cadmium to aquatic organisms varies with the type and life stage of organisms, presence of other toxicants, duration of exposure, and hardness. In acute tests cadmium accumulates in gill tissue to a greater extent than elsewhere, whereas, in chronic tests at lower concentrations, cadmium accumulates more in liver and kidney tissue. The principal acute effect is disruption of calcium balance in the blood leading to hypocalcaemia and death (*Niyogi et al. 2008*). Chronic mechanisms of toxicity are poorly understood but may similarly involve calcium imbalance, but with the kidney and liver as the primary site of action rather than the gill (*Wood et al. 1997*).

Evidence for joint toxic effects of cadmium in mixtures with other chemicals is confusing and appears contradictory, even for the simplest two-chemical mixture tests. Cadmium and zinc often co-occur in the environment and have some similar chemical properties (e.g., both act as calcium channel blockers leading to hypocalcemia and death in fish). Reports of whether cadmium is more toxic in the presence of other metals, less toxic, or no different have been contradictory (*Norwood et al. 2003*). For instance, Glynn et al. (*1992*) found that Cd+Zn mixtures were more toxic to minnows than when tested alone. In contrast, other studies found that the toxicity of Cd+Zn mixtures to rainbow trout was similar to that of each metal acting independently (e.g., *Hansen et al. 2002*; *Mebane et al. 2010*). Other studies have reported little or no increase in toxicity when cadmium was tested with other chemicals (mostly metals) in various combinations with Chinook salmon, American flagfish, Daphnia, and amphipods (*Spehar et al. 1978*; *Attar and Maly 1982*; *Finlayson and Verrue 1982*; *Keller and Zam 1991*; *Gust 2006*; *Birceanu et al. 2008*). In contrast to the often small additive effect of Cd+Zn mixtures, Cd+Cu mixtures might be more toxic than either alone. Copper has been reported to increase the toxicity of cadmium and vice versa in exposures of benthic communities to Cd+Cu mixtures in experimental streams, with *Daphnia magna*, and possibly Chinook salmon, although for the latter the magnitude of apparent increased toxicity was not great (*Finlayson and Verrue 1982*; *Clements 2004*; *Barata et al. 2006*). Playle (*2004*) suggested that whether metals in combination are more or less toxic than separately depends not just on the metal, but on the relative ratios concentrations of metals, which greatly complicates making simple rules of thumb about which metals combinations have increased or decreased toxicity risk. However, he argued that metal speciation and toxicity models (e.g., biotic ligand models, BLMs) provide a means to reconcile multiple-metal toxicity results (*Playle 2004*).

Overall, the conflicting information does not provide a clear answer to the question. However, it does lead to the conclusion that site-specific assessments of cadmium risks that can integrate joint effects would be beneficial, such as benthic community monitoring or whole-effluent toxicity (WET) testing of whole water samples.

3. DIRECT EFFECTS OF PROPOSED CADMIUM CRITERIA

Cadmium toxicity is correlated with water hardness, and both existing and the proposed criteria are hardness-dependent. At hardness of 50 mg/L $CaCO_3$, the acute and chronic National Toxics Rule (NTR) values (*USEPA 1992*) which USEPA presently considers effective pending their proposed action, are 1.75 µg/L and 0.62 µg/L, respectively. The proposed action would replace these with updated cadmium criteria adopted by Idaho in 2006. Idaho's updated and currently effective cadmium criteria at a hardness of 50 mg/L are 0.75 µg/L and 0.37 µg/L, respectively (Table 1).

3.1. Acute Cadmium Criterion

Available toxicity test data indicate that listed salmonids are likely to be adversely affected by cadmium concentrations equal to the existing NTR acute criterion, and that a substantial fraction would still be adversely affected at the updated lower acute criterion that is proposed for approval.

Interpreting and reviewing an aquatic life criterion requires keeping straight an abundance of terms and their abbreviations that are peculiar to the subject. This discussion and Table 2 are an attempt to briefly summarize key terms and steps in the process. For the "acute criterion" to protect against short-term exposures, the criterion is constructed from LC50 values for a variety of organisms. The LC50 is the concentration that killed 50% of the organisms in a toxicity test. The LC50 is the summary statistic that is almost always reported for tests. For conservation purposes, a preferred statistic would be one for the threshold of no-appreciable toxicity, rather than a statistic for killing half. However, it has not been the common practice of ecotoxicologists to do so, and LC50 data generally are the best data that is readily available. Because criteria are not supposed to kill 50% of sensitive organisms, at the end of the process an adjustment is needed to have a mostly non-lethal criteria as opposed to a lethal criteria.

To derive an acute criterion value, all the acceptable LC50s that can be found for a species are used to get a SMAV, the SMAVs are rolled up to genus mean acute values (GMAVs), and the GMAVs are rank ordered from least sensitive to most sensitive. The 5th percentile of the GMAVs is calculated and is called the Final Acute Value (FAV). Generally, the USEPA criteria scheme assumes that protecting all but the most sensitive 5% of the species is good enough. However, with cadmium, the most sensitive species that would not be protected under a scheme to protect all but the most sensitive 5% are salmonid species that are socially valued and two, bull trout and steelhead, are protected under the ESA. Therefore, the FAV in the proposed criteria was lowered to the most sensitive SMAV (cutthroat trout), instead of the 5th percentile of the SMAVs. But, because the FAV is an estimate for a concentration lethal to 50% of the species that, on the average, is most sensitive to cadmium the FAV is divided by 2 to extrapolate from a lethal concentration to one expected to kill few animals (Table 2). For this review, to compare the protectiveness of the criterion for listed species, LC50s from toxicity tests with listed species or their surrogates were compared to the FAV, not the criterion. This approach keeps the units straight in the comparison (LC50s to a statistic based on LC50s). The acute criteria, which are the FAV/2, cannot be compared directly with other LC50s unless they too were similarly divided by two. This approach was avoided because it would blur what is "data." The assumption that simply dividing a LC50 by 2 will reliably extrapolate from a concentration killing 50% of a test population to one killing few if any is obviously fundamental to USEPA's (*2010*) and the present analysis. This assumption was generally supported for other chemicals in work comparing the sensitivity of endangered and threatened fishes to "standard" (commonly tested) laboratory species (*Dwyer et al. 2005*), and was upheld in a toxicity test examined in detail here as part of the " *hardness cap*" issue. There, dividing the LC50 by 2 would result in a concentration killing no fish (*Table 4*).

Table 2. Relationships between selected species mean acute values (SMAVs), the Final Acute Value (FAV), and the acute criterion for cadmium. An acute value is the concentration from a test that killed 50% of theorganisms (LC50)

Sensitivity ranking (least to most sensitive)	Species	SMAVs (µg/L, adjusted by hardness-toxicity regression to a hardness of 50 mg/L	Range of LC50 values that made up the SMAV, adjusted to a hardness of 50 mg/L
69	Flatworm (Planarian)	15540.	–
(skipping to the most sensitive species…)			
5	Chinook salmon	2.67	2.3 to 3.3
4	Mottled sculpin (Cottus bairdi)	2.56	1.6 to 4.5
3	Bull trout (Salvelinus confluentus)	2.13	1.4 to 4.5
2	Rainbow/steelhead trout (*O. mykiss*)	2.04	0.61 to 9.3
1	Cutthroat trout (O. Clarki)	1.50	0.72 to 2.1
FAV calculated as the 5th percentile of the 69 SMAVs		2.45	
FAV lowered to be equal to the SMAV for the most sensitive "important" species (Cutthroat trout). The FAV would therefore be expected to kill 50% of the cutthroat trout		1.50	
Acute criteria is the FAV ÷ 2 to extrapolate from a concentration expected to kill 50% of the sensitive species to a concentration assumed to kill few individuals		0.75	

The majority of LC50s for juveniles within the genus *Oncorhynchus* were below the NTR final acute value (FAV) concentrations (*Figure 2*). Instances of significant mortality were also recorded below Idaho's updated criteria; the pattern of data suggests that some life stages or stocks could be more sensitive than the criteria value. More specifically, for juvenile Chinook salmon, 60% (3 of 5) of the LC50s reviewed were less than (i.e., not protected by) the older NTR FAV that is being replaced by the current action. For juvenile rainbow/steelheads, 87% (34 of 39) of the values were not protected by the NTR FAV, and for juvenile bull trout, 66% (4 of 6) values were not protected by the NTR FAV. (Although not part of this evaluation, bull trout were included in the comparison because they are also an ESA listed species and they co-occur with Chinook and steelhead.) In contrast, none of the juvenile Chinook salmon or sockeye salmon LC50s were below the Idaho FAV. For juvenile rainbow/steelheads, about 23% (8 of 35) and for juvenile bull trout, 33% (2 of 6) of the acute values were below the Idaho FAV (*Figure 3*). Therefore, the effect of the action, replacing the NTR cadmium criterion with the

Idaho cadmium criterion is more protective than the old NTR cadmium criterion, which was clearly unprotective. However, a substantial proportion of rainbow/steelhead would not be completely protected by the acute Idaho criterion (Figure 3), and therefore it is necessary to evaluate whether "conservative measures" described in USEPA (*2010*) would be effective in reducing allowable cadmium exposures that would be unlikely to result in take of any listed fish.

The data reviewed suggest that the larger swim-up stage salmon and steelhead are probably most susceptible to lethal effects of cadmium concentrations allowed under the proposed criteria. For these species, larger swim-up stage fish are probably around 0.5 to 1.5g or so in weight. Eggs, embryos, alevins, and new swim-up stage (e.g., weighing less than <≈ 0.2 to 0.3g) listed salmon and steelhead are less sensitive to short-term exposures to elevated dissolved cadmium concentrations than the larger, swim-up fry, and unlikely to be affected by the proposed acute criterion. Adults and juvenile salmonids older than swim-ups are less sensitive to metals in general, although the evidence specific to cadmium is equivocal (*Chapman 1978*; *Chapman and Stevens 1978*; *Mebane 2006*).

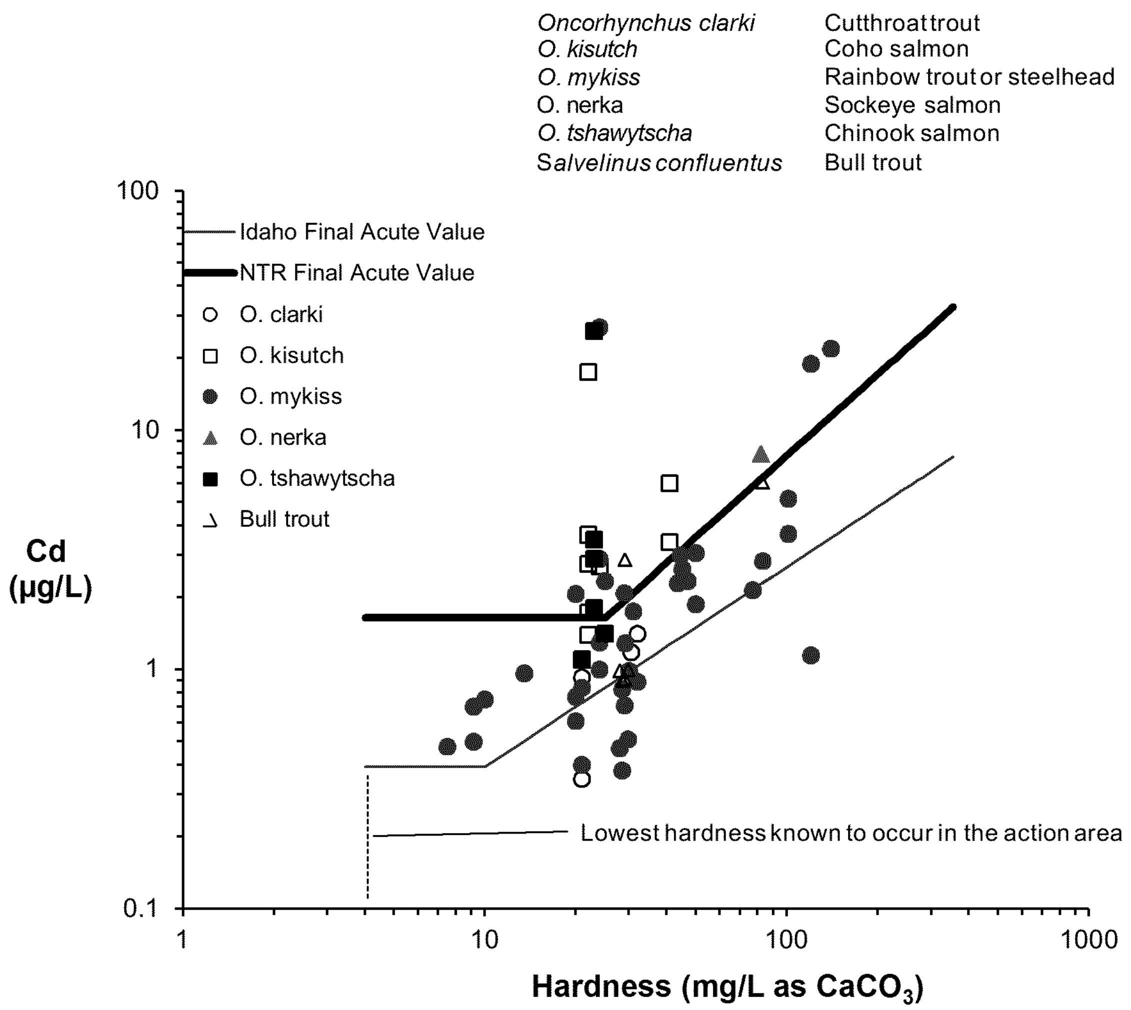


Figure 2. Comparison of selected 96-hour LC50s for cadmium and comparable criterion final acute values. LC50s limited to species within the genus *Oncorhynchus* and bull trout. The bend in the FAV lines represent the "hardness caps" where it was assumed in the action that the general pattern of increasing toxicity (lower LC50s) with decreasing hardness will cease.

3.2. Chronic Cadmium Criterion

Most available salmonid toxicity test data indicate that the Idaho chronic criterion proposed for approval would be unlikely to cause overt adverse effects to salmonids, such as reduced survival, growth, or reproductive success (*Figure 4*, *Table 2*). A single exception was a chronic test with rainbow trout in which reduced growth was observed at treatment concentrations less than the Idaho criteria. In this test reduced growth occurred in all cadmium concentrations tested compared to the streamwater control without added cadmium. However, how to evaluate these effects is not self-evident, because no concentration response occurred, that is, growth inhibition did not increase in severity with increased concentrations (*Mebane et al. 2008*). This result stands apart from effects reported in the six other chronic tests with rainbow trout or in the single

Chinook salmon test reviewed (*Figure 3*, *Table 2*). Thus, the preponderance of the relevant data indicates that frank adverse effects are not expected at concentrations lower than the chronic criteria. The potential for maladaptive behavioral effects are discussed separately as follows.

3.2.1. Behavioral Effects

Cadmium has been shown to cause neurotoxic effects in fish at environmentally relevant concentrations. These neurotoxic effects may manifest themselves through altered behavior, which in turn may predict more serious effects including reduced growth, reproductive failure, and death. Hyperactivity probably is the most widely observed maladaptive behavior reported from cadmium exposed fish, with several reports involving a variety of fish species during long-term cadmium exposures. Most fish that exhibited hyperactive behavior in long-term exposures ultimately died. Hyperactivity is detrimental to small fish because it makes them more likely to be seen and attacked by predatory fish. Similarly, hyperactive predatory fish have lower success rates in detecting, orienting to, attacking, and swallowing prey. Except for four tests with brook trout and lake trout, these effects were only observed following cadmium exposures at concentrations greater than the chronic criterion (*Baker and Montgomery 2001*; *Phillips 2003*; *Scott et al. 2003*; *Sloman et al. 2003*; *Riddell et al. 2005a*; *Mebane 2006*).

Studies that showed maladaptive behaviors at environmentally relevant conditions that are close to the criterion suggest that salmonids in the genus *Salvelinus* may be particularly sensitive to cadmium neurotoxicity, and may be more sensitive than the Pacific salmon and trout in the genus *Oncorhynchus* that are the subject of this analysis. Adverse effects to lake trout and brook trout have been observed in stream or pond mesocosm experiments at concentrations below either the NTR or the lower Idaho chronic criterion (*Kislalioglu et al. 1996*; *Riddell et al. 2005a*; *2005b*). One test jointly exposed rainbow trout prey and lake trout predators to 0.5 µg/L cadmium for eight months, a concentration lower than the NTR and about equal to the Idaho chronic criteria. The exposures were apparently adverse to the lake trout but not to the rainbow trout (*Scherer et al. 1997*). None of the limited data located and reviewed indicated appreciable adverse effects to salmonids in the genus *Oncorhynchus* at concentrations below the current Idaho chronic criteria.

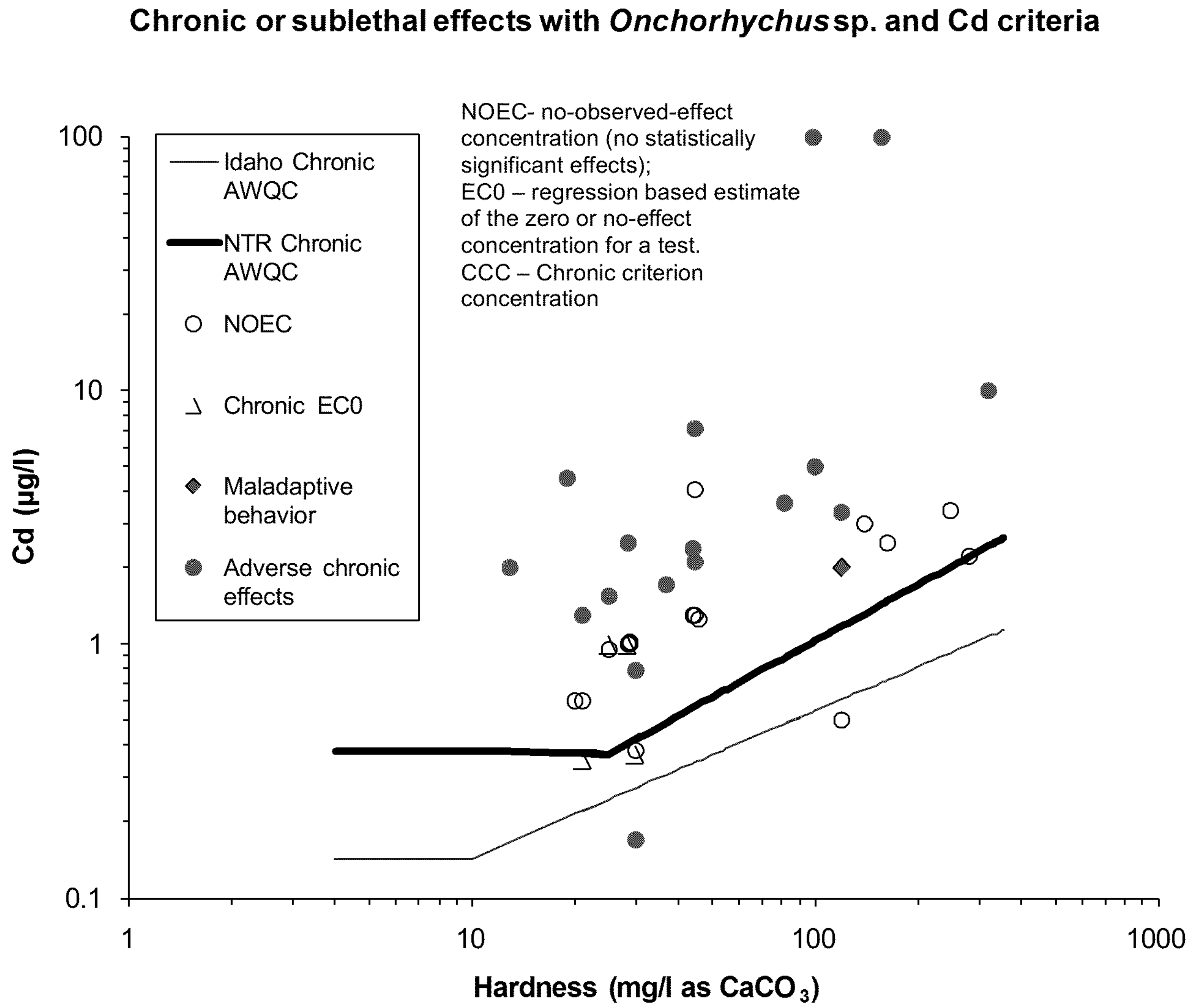


Figure 3. Comparison of chronic criteria and selected adverse chronic or sublethal effects and estimates of no-effects. Data limited to species within the genus *Oncorhynchus* and bull trout *(Salvelinus confluentus)*. NOEC – no observed effect concentration from null hypothesis statistical tests, EC0-estimated concentration causing zero effect from nonlinear regression analysis.

Table 3. Selected data on effects of cadmium to listed species, surrogates, or prey. Underlined values indicate adverse effects at concentration lower than the allowable criteria values (NTR-National Toxics Rule, FAV – Final Acute Value, FCV – Final Chronic Value)

Species	Size or age	Time (days)	Effect	Statistic used to describe effect	Hard-ness (mg/L)	Effect value (µg/L)	FAV or FCV (NTR)	FAV or FCV (Idaho)	Source/notes
Chinook salmon *(Oncorhynchus tshawytscha)*	Alevin, 0.05 g, 1-day old	4	Death	LC50	25	27.00	1.6	0.8	(*Chapman 1978*)
—	swimup fry, 0.8 g	4	Death	LC50	25	1.41	**<u>1.6</u>**	0.8	(*Chapman 1978*)
Sockeye salmon (*O. nerka*)	Fry	7	Death	LC50	83	8	6.1	2.3	(*USEPA 2001, citing Servizi and Martens 1978)*)
Coho salmon *(O. kisutch)*	2-weeks posthatch (alevin)	4	Death	LC50	22	1000	1.6	0.8	(*Chapman 1975, as cited by Mebane (2006), Table 17*)
—	4-weeks posthatch (swim-up)	4	Death	LC50	22	3.66	1.6	0.8	(*Chapman 1975, as cited by Mebane (2006), Table 17*)
—	7-weeks posthatch (swim-up)	4	Death	LC50	22	1.40	**<u>1.6</u>**	0.8	(*Chapman 1975, as cited by Mebane (2006), Table 17*)
—	21-weeks posthatch (parr)	4	Death	LC50	22	2.70	1.6	0.8	(*Chapman 1975, as cited by Mebane (2006), Table 17*)
—	Adult	4	Death	LC50	22	17.5	1.6	0.8	(*Chapman and Stevens 1978*)
—	Adult	9	Death	LC50	22	3.7	1.6	0.8	Chapman and Stevens, 1978
Rainbow/ steelhead *(O. mykiss)*	Juvenile	4	Death	LC50	9	0.50	**<u>1.6</u>**	**<u>0.8</u>**	(*Cusimano et al. 1986* (pH 7)
—	Juvenile (1 g)	4	Death	LC50	29	0.38	**<u>2.0</u>**	**<u>0.6</u>**	(*Hansen et al. 2002*) Most sensitive of 35 values reviewed by, Mebane (2006),

Species	Size or age	Time (days)	Effect	Statistic used to describe effect	Hard-ness (mg/L)	Effect value (µg/L)	FAV or FCV (NTR)	FAV or FCV (Idaho)	Source/notes
—	Juvenile (4.5g)	4	Death	LC50	140	22.00	10.6	1.5	(*Hollis et al. 1999*) Least sensitive of 35 values reviewed by, Mebane (2006),
—	Juvenile	4	Death	LC50	50	2.07	**3.6**	1.5	Geometric mean of 35 tests, Mebane 2006. Table 15
—	Early life stage	53	No effect	EC0	20	0.35	0.4	0.2	Appendix C
—	Early life stage	62	Reduced growth	LOEC	29	0.17	0.41	0.27	Mebane et al. 2008; effects not concentration dependent
—	Early life stage	~60	No effect	NOEC	50	1.2	0.7	0.4	Geometric mean of 6 tests, Mebane 2006, Table 14
Chinook salmon	Early life stage	120	No effect	EC0	25	1.0	0.4	0.3	Calculated from Chapman, (1982) data
Brook trout (*Salvelinus fontinalis)*	Fry	30	Impaired prey capture and reduced growth	LOEC	156	0.4	**1.4**	**0.77**	(*Riddell et al. 2005a*; *2005b*)
Amphipod, *Hyalella azteca*	Juveniles	28	Reduced growth	EC25	130	0.57	**1.25**	**0.69**	(*Ball et al. 2006*)
Amphipod, *Hyalella azteca*	Population	6y	Little risk of extinction		280	1.0	**2.5**	**1.1**	Mebane, 2006
Amphipod, *Hyalella azteca*	Population	6y	Near certainty of extinction		280	2.2	**2.5**	1.1	Mebane, 2006

4. THE "HARDNESS CAP" ISSUE

Water hardness is used as predictor of cadmium toxicity in both the existing NTR and proposed updates. That is, the cadmium criteria are calculated as a function of hardness (Table 1). Water hardness is a shorthand term for the amounts of calcium and magnesium in water. Calcium hardness clearly ameliorates cadmium toxicity (*Reid and McDonald 1988*; *Niyogi et al. 2008*). However, most studies that manipulated hardness either varied both calcium and magnesium together or only calcium, so there is little evidence that magnesium ions ameliorate cadmium toxicity. Carroll et al (*1979*) and Davies et al (*1993*) showed experimentally that magnesium ions provide little protection against acute or chronic cadmium toxicity in fish, respectively. However, in most waters calcium and magnesium are correlated, so unless a water had unusually low Ca:Mg ratios, which is uncommon in the action area, "hardness" will mostly be calcium hardness (*Donato 2004*; *Hardy et al. 2005*).

Mechanistic studies of cadmium toxicity in fish reveal that cadmium inhibits enzyme-mediated calcium uptake in the gills (*Verbost et al. 1989*). Unlike some other metals such as copper and lead, dissolved organic carbon (DOC), has little effect on cadmium bioavailability and toxicity(*Playle et al. 1993*). In natural waters, hardness, pH, and alkalinity interact to affect cadmium toxicity. These factors often correlate with hardness measures. As a result, hardness has been reported to be a practical surrogate for factors modifying cadmium toxicity (*Mebane 2006, his figure 2*).

4.1. Would the low-hardness "cap" be protective at the lower hardnesses that actually occur?

In the existing NTR cadmium criteria and in the Idaho criteria proposed for approval, the hardness-toxicity relation is "capped" at minimum hardnesses of 25 mg/L and 10 mg/L respectively. That is, the relation of increasing toxicity associated with reduced hardness is assumed to stop at a hardness of 25 mg/L and, in waters with lower ambient hardnesses, a fixed value of 25 or 10 mg/L is used in the criteria equations instead. The rationale for the cap is that there had been few toxicity tests conducted at hardnesses less than 10 mg/L, and therefore, there was no proof that the general relationship of cadmium becoming more toxic as hardness declined continued beyond the range of tested conditions. However, no evidence or rationale was found explaining why the toxicity-hardness relation would not be expected at extend to lower hardnesses (*USEPA 2010, especially appendix B*).

This presents a logical problem with the proposal to lower the cadmium criteria hardness-cap of 25 mg/L to 10 mg/L. The problem is, the lowest water hardness expected within the action area is not 10 mg/L, but is closer to 4 mg/L (*Donato 2004*). Would the Idaho cadmium criterion of 0.2 µg/L (capped at a hardness of 10 mg/L) be protective down to the lowest hardnesses that actually occur, which are about 4 mg/L? If the hardness-cap of 25 mg/L is unprotective because cadmium continues to be increasingly toxic as hardness falls below 25 mg/L, what is to say it won't continue to increase in toxicity below a hardness of 10 mg/L? The answer is probably that cadmium does become increasingly more toxic at even lower hardness values, but that toxicity testing is not a trivial undertaking (*e.g., ASTM 1997*) and no one has happened to test those conditions.

Therefore, the question becomes "at the minimum capped acute criterion of 0.2 µg/L, would cadmium toxicity be expected down to the lowest hardness expected for the action area (4 mg/L)?" To evaluate this, the data details underlying the toxicity test that was the "nearest neighbor" to the minimum expected hardness was examined. This test was conducted in a stream in northern Idaho during snowmelt. To our knowledge, this test represents the softest water (7.5 mg/L) ever known to have been tested in a toxicity test with rainbow trout or other sensitive and relevant species (*Figure 2, the data point plotted furthest to the left*).

The analysis of this test indicated that there is probably just enough leeway in the cadmium criteria that the concentration resulting from the criteria equation calculated at a "capped" false minimum hardness of 10 mg/L (0.2 µg/L cadmium) would be predicted not to kill any fish even if the true hardness was 4 mg/L. In contrast, a concentration only 2 times higher (0.4 µg/L cadmium at a hardness of 4 mg/L) would be expected to kill 100% of the fish. Details of these calculations are shown in *Table 3*.

Note that this analysis and conclusion are distinct from the separate problem that at higher hardnesses, some mortality could be expected due to differences in size-sensitivity or from other unexplained factors relating to the strain or robustness of different test fish (i.e., discussions related to points falling below the FAV line in *Figure 2* or the distribution of sensitivities in *Figure 3*).

Table 4. Calculations extrapolating toxicity from the lowest-hardness test ever conducted with a salmonid and cadmium to the lowest water hardness expected within the action area

Hardness cap Cd toxicity evaluation

Cd toxicity to rainbow trout, results from the test conducted at the lowest hardness water known to be tested (Little North Fork of the SFCDA River during spring melt, 5/23/99 (Windward, 2000)

LC50 (µg/L)	Hardness
0.48	7.5

But LC50's aren't a measurement, they are actually a statistic modeled from 5 concurrent experiments, where in this case treatment 1 (0.35 µg/L Cd) killed no fish, and treatment 2 (0.65 µg/L) killed all fish. These are the "no observed adverse effect concentrations" and the "lowest observed adverse effect concentration" (NOEC and LOEC). These are termed "observed" because obviously the onset of severe effects would be at some concentration in between, but there were no observations between treatments 1 and 2. The calculated LC50 is in between these two values.

	Hardness	Treatment Cd (µg/L)	Number of Survivors	Number Exposed	Mortalities (%)
Control	7.5	0.1	19	20	5
Little North Fork, 1	7.5	0.35	20	20	0
Little North Fork, 2	7.5	0.65	0	20	100
Little North Fork, 3	7.5	1.14	0	20	100
Little North Fork, 4	7.5	2.2	0	20	100

Extrapolating this test to the minimum expected hardness in Idaho (4 mg/L) using the same hardness-toxicity relation as in the criterion yields:

LC50 (µg/L)	Hardness
0.28	4

And likewise extrapolating the actual treatment concentrations gives us:

	Hardness (mg/L)	Extrapolated treatment Cd (µg/L)	Number of Survivors	Number Exposed	Mortalities (%)
Control	4	0.06	19	20	5
Little North Fork, 1	4	0.21	20	20	0
Little North Fork, 2	4	0.38	0	20	100
Little North Fork, 3	4	0.67	0	20	100
Little North Fork, 4	4	1.30	0	20	100

(Extrapolated treatment concentration at hardness 4 mg/L is similar to CMC at hardness 10 mg/L (0.21 vs 0.20 µg/L)

	Percent
Expected rainbow trout deaths from Cd at the 2006 CMC value to rainbow trout under a hardness cap of 10 mg/L, extrapolated to the lowest hardness on record (4 mg/L):	0
Expected rainbow trout deaths from Cd at the 2006 CMC value to rainbow trout under a hardness cap of 25mg/L, extrapolated to the lowest hardness on record (4 mg/L):	100

5. INDIRECT EFFECTS OF PROPOSED CADMIUM CRITERIA

5.1. Toxicity of cadmium to prey organisms of listed species

Aquatic macroinvertebrates, which serve as significant food sources for early life stages of listed salmon and steelhead, as well as for other aquatic organisms that are in turn prey items, are sensitive to cadmium. Invertebrate communities in rivers appear to respond to elevated cadmium levels in sediments and water by changing composition to metals-tolerant taxa, rather than by reducing overall biomass (*Maret et al. 2003*). For juvenile salmonids, feeding on mayflies is most profitable and some metals-tolerant taxa such as chironomid midges are less nutritious than mayflies (*Descroix et al. 2010*). Cadmium-exposed mayflies and midges may also be less palatable to juvenile salmonids, based on experiments in which non-cadmium exposed brook trout took longer to swallow cadmium exposed mayflies and midges than non-cadmium exposed mayflies and midges (*Riddell et al. 2005b*).

Whether cadmium is toxic to invertebrates is influenced by the manner in which invertebrates were exposed to cadmium. Ball et al. (*2006*) exposed *Hyalella* to algae that had been grown in different cadmium concentrations. Adverse effects (25% reduced growth) occurred at only 0.57 µg/L cadmium, tested in water with a total hardness of 130 mg/L. This exposure was almost the same as the chronic criterion proposed for approval (0.64 µg/L) and twice as low as the previously approved criterion of 1.25 µg/L.

Cadmium is taken up quickly by sediments but is readily remobilized through a variety of physical, chemical, and biological processes (*Currie et al. 1997*). Cadmium contained in bed sediments appears to be bioavailable to benthic invertebrates and has been found to be elevated in benthic invertebrates in field studies conducted in metals-contaminated streams (*Farag et al. 1999*; *Besser et al. 2001*; *Farag et al. 2007*). Field surveys of macroinvertebrates from sites ranging from pristine to those polluted with greater than 100 times background levels of cadmium and zinc have been related to chronic cadmium criteria exceedence factors. Patterns of invertebrate taxa richness or densities in scatter plots suggest some reductions are associated with cadmium concentrations at less than chronic criterion concentrations. However, taxa richnesses and densities of "sensitive" stream invertebrates (certain mayflies, stoneflies, a caddisfly, and a true fly) were generally high at sites until the Idaho chronic cadmium criterion was exceeded by five or more times (*Mebane 2006, at figure 6*).

One invertebrate, the amphipod *Hyalella azteca*, may be particularly sensitive to cadmium. It is the only species with a species mean chronic value that is lower than either the NTR or the Idaho chronic criteria. Six chronic tests with *Hyalella* were analyzed by Mebane (2006), in all six tests adverse effects would be expected at the existing Idaho chronic criterion concentration. The magnitude of adverse effects at the lower Idaho chronic criteria proposed for approval ranged from 10% reduction in survival or fecundity to greater than 50% mortalities.

The USEPA (*2010*) also noted that *Hyalella* was sensitive to cadmium but, noting that some laboratories have had regular or intermittent difficulty culturing and testing *Hyalella*, discounted all data from any laboratory with cadmium and *Hyalella* from their evaluation. In support of this judgment, USEPA (*2010*) noted that unpublished data indicates that *Hyalella* do best when chloride concentrations in culture waters are between 25 and 100 mg/L. In the Snake River basin, other than geothermal springs, waters with chloride concentrations greater than 25 mg/L tend to be polluted by agricultural runoff, such as the Snake River at King Hill, Idaho. At a U. S. Geological Survey monitoring location on the lower Snake River at Burbank, Washington, where *Hyalella* and other amphipods are commonly collected, the median chloride value is about 8 mg/L. Similarly, *Hyalella* were collected from the Pahsimeroi River where chloride concentrations are about 7 mg/L. In other areas of Idaho that are outside the Snake River salmon and steelhead ESUs but are probably similar to waters with the ESU, *Hyalella* have been collected from waters with chloride concentrations of <1-2 mg/L (e.g., St Joe River near Calder, Idaho, Spokane River near Post Falls, Idaho, Lake Coeur d'Alene). Thus, only considering data from tests with chloride between 25 and 100 mg/L may not be representative of many natural freshwaters. For these reasons, and because situations in which some laboratories have regular or intermittent culturing or testing difficulties are not unique to *Hyalella*, USEPA's (2010) recommendation to discount all studies with this amphipod is not used here.

Amphipods are benthic crustaceans that occupy an intermediate position in freshwater food webs between detritus and predators, such as salamanders and salmonids (*Mathias 1971*). Amphipods are sometimes abundant in lakes and slow-moving rivers. Salmonids and other fish readily prey upon amphipods, probably consuming them in rough proportion to their abundance relative to other vulnerable invertebrates. For example, in the lower Snake River in Washington and Idaho, amphipods contributed 2.7% and 7.9% of identifiable prey categories found in the stomachs of juvenile Chinook salmon and steelhead respectively from Lower Granite Reservoir, (7th and 5th most important prey categories, respectively (Karchesky and Bennett 1999). Amphipods were important in sockeye salmon diets in a British Columbia lake; however, that may not be the case with sockeye salmon in Idaho lakes. In dietary studies, there was no mention of amphipods in the stomach contents of endangered sockeye salmon or kokanee salmon in nursery lakes in Idaho (*Landres et al. 1988*; *Steinhart and Wurtsbaugh 2003*; *Teuscher 2004*).

However, because so few other benthic macroinvertebrates have been tested with cadmium in long-term or environmentally realistic settings, it may be appropriate to consider *Hyalella* responses as surrogate responses for sensitive benthic invertebrates rather than just relating to *Hyalella* in isolation.

Mebane (2006) attempted to relate the predicted effects of cadmium to this species to fish populations or other indirect effects on aquatic ecosystems, in part, by simulating effects of cadmium to a natural, coldwater *Hyalella azteca* population. This involves using mathematical population models that integrate toxicity testing results with ecological theory. The population modeling considered three scenarios where:

1. Population growth rates were calculated for a range of constant cadmium concentrations. Population growth rates have been considered more ecologically relevant than single test endpoints because they integrate both survival and reproduction;

2. Risk of population decline statistics were calculated across a range of constant cadmium concentrations. In contrast to the first deterministic scenario, these scenarios recognized the intrinsic unpredictability of natural systems (stochasticity) and used random simulations based on parameter variability estimates; and

3. Seasonal population trajectories for several years under (a) baseline conditions without any added cadmium stress; (b) adding constant exposure to cadmium at the chronic criterion; and (c) an episodic exposure scenario in which the animals were exposed to criterion exceedences at the frequency allowed by the criteria with magnitudes that were considered plausible (*Mebane 2006*; *2010*).

The modeling predicted that at the NTR chronic criteria (2.2 µg/L at the scenario hardness of 280 mg/L) quasi-extinction of the population was highly likely, with greater than 80% probability of a greater than 98% population decline occurring during the 6-year modeling scenario. At the Idaho chronic criteria (1.0 µg/L at the scenario hardness of 280 mg/L), the likelihood of extinction or severe decline during the 6-year modeling scenario was low (0.1% probability of a 98% reduction and less than a 2% chance of a 95% decline. Because *Hyalella* were predicted to have highly variable populations, even under baseline conditions (no cadmium risk), there were even odds of up to a 75% decline occurring; that risk was slightly higher (about 60%) at the Idaho chronic criteria.

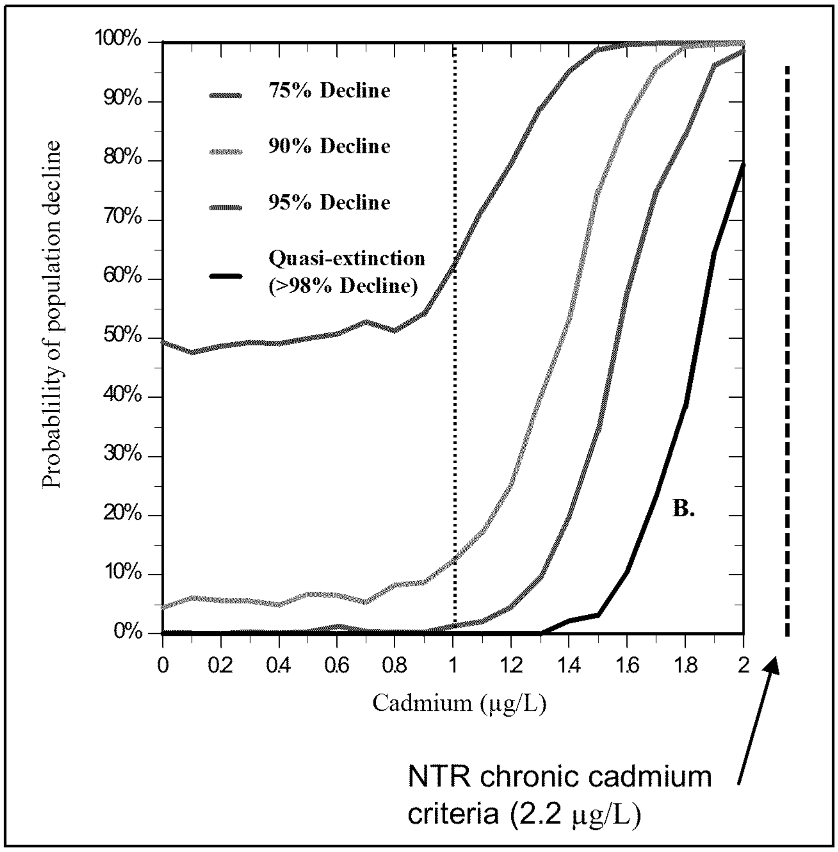


Figure 4. Population modeling of the effects of continuous Cd exposures on *Hyalella azteca* populations. The Idaho chronic criteria of 1 µg/L for the conditions modeled (light vertical dashed line) was predicted to have only marginally increased risk of population decline and almost zero risk of extinction .Negative population growth rates and quasi-extinction were predicted to be inevitable at the former NTR chronic criteria (heavy vertical dashed line)

In summary, extinction of populations of a sensitive prey species, the amphipod *Hyalella azteca* would be predicted under continuous exposure to the NTR chronic criterion concentrations; extinction of *Hyalella* under the Idaho chronic criterion that is proposed to replace the NTR criterion would be very unlikely. *Hyalella* are probably not an essential food item of listed anadromous salmonids in the action area, and probably around 10 to 40 species of benthic macroinvertebrates occur at any given monitoring sample. Thus, if the projected effects to *Hyalella* were considered to only be relevant in and of themselves, then effects to *Hyalella* could be discounted. However, if because so few benthic invertebrate species have been tested in chronic tests (i.e., 5 of ≈10,000 species, Mebane 2006, p5) and because of arguments that water-only toxicity tests with benthic macroinvertebrates systematically under-predict sensitivity to metals (*Besser et al. 2005*; *Ball et al. 2006*; *Buchwalter et al. 2007*), the *Hyalella* story is considered a surrogate for other, untested, and potentially sensitive benthic macroinvertebrates.

5.2. Toxicity of cadmium accumulated in prey organisms to listed salmonids

The previous section concluded that cadmium at the proposed criteria concentrations would be unlikely to reduce the amount and diversity of prey items required by listed salmon and steelhead. The following considers whether cadmium would likely accumulate in prey organisms to the point that dietary exposure to cadmium could be harmful to salmonids.

Most results suggest that risks of reduced growth or survival (the most commonly tested effects) were unlikely. A way of estimating the potential concentrations of cadmium in prey organisms eaten by salmonids is through a "toxic screening concentration" (TSC) for tissue residues that multiplies the proposed chronic criterion by a bioaccumulation or bioconcentration factors (*Dyer et al. 2000*). Bioconcentration factors (BCFs) or bioaccumulation factors (BAFs) are quantitative estimates of bioaccumulation. When derived from laboratory tests where the only route of exposure to elevated concentrations is from their water, the term BCF is used to express the ratio of internal concentrations in the organs or whole body of the organism to the concentrations in water; when derived from field studies where exposure is through both food and water, the term BAFs is usually used. Of the two, BAFs are more ecologically relevant.

The BAFs and BCFs are notoriously uncertain (*McGeer et al. 2003*). Using the TSC approach of Dyer et al (*2000*), gives a wide range of predicted tissue residues that could be expected from the criterion proposed for approval. Using a compilation of laboratory water-only exposures to cadmium, McGeer et al. (*2003*) calculated a mean BCF for cadmium to be around 2623, but also calculated a lower accumulation factor of 352 that resulted when the literature values were "corrected" for background residues. In contrast to this analysis, which used water-only laboratory data, Mebane (*2006*) calculated a range of about 88 to 4260 with a mean of 1340 for BAFs from various published field studies or experimental ecosystems. The USEPA (*2010, p.52*) used a similar approach to estimating cadmium whole-body residues associated with adverse effects to aquatic organisms, except that they used a BAF of 38. Their BAF estimate of 38 was far lower than any of the other BAFs estimates reviewed. No explanation of the source or calculation of the BAF value of 38 was located in USEPA (*2010*).

Using McGeer et al's 352 - 2623 range of BCF values, because it encompassed Mebane's mean BAF of 1340, the higher BCF would result in TSCs of about 3 - 15 mg/kg dry weight in organisms whereas their lower "corrected" accumulation values would predict only about 0.4 to 2 mg/kg dry weight.

These predicted tissue residues would be lower than most studies on the effects of cadmium in the diet of salmonids. The toxicity of dietborne metals is a major area of contemporary research and with results that are hard to synthesize. One area of controversy and contradictory results has to do whether dietborne metals are exposed "artificially" by spiking metal salts into manufactured food pellets, or exposed to fish more naturally by rearing worms or other live prey items in metal-spiked water or sediment, and then feeding the live worms to fish (*Meyer et al. 2005*). Here, it is assumed that metals "naturally" incorporated into the proteins of worms are the more relevant exposure. Under this assumption, salmonids exposed to dietborne cadmium via live prey suffered no measureable ill effects up to about 90 mg/kg Cd, as dry weight (*Erickson et al. in press*). Reduced growth in similarly exposed rainbow trout did cause reduced growth at about 180 mg/kg dw (*Ng and Wood 2008*), but this is far higher than the theoretical residue concentrations calculated above as the product of the CCC and BAF or BCF (<15 mg Cd/kg dw). In a subsequent experiment, Ng et al (*2009*) observed reduced growth at much lower concentrations of cadmium in the diet (12 mg Cd/kg dw), which is in the range predicted here from the proposed criteria. However, in this latter study, the exposure was not through a live diet but a pelletized worm diet spiked with cadmium nitrate. Thus, the best information available suggests that the likelihood of adverse effects to listed salmon and steelhead resulting from cadmium accumulated in prey items is very low.

6. SUMMARY OF EFFECTS: CADMIUM

The updated Idaho acute cadmium criteria proposed for approval is generally more protective than the older criteria it would replace both because it would allow lower concentrations, but also because it has a lower hardness cap. For Chinook salmon and sockeye salmon, the updated acute criteria is lower than any acute effects data located (Figure 2, Table 3). However, with rainbow/steelhead trout, even with the lower, updated acute Idaho cadmium criterion proposed for approval, there is still an appreciable risk of mortality at criterion concentrations (Figure 2), with about 23% of the test values reviewed suggesting mortality. The risk of mortality likely varies with the life stage or size of fish at the time of their first exposure and acclimation. Early migratory stages of listed salmon and steelhead are more likely to be susceptible to lethal effects of cadmium at concentrations allowed by the proposed acute criterion than eggs, embryos, and alevins.

Therefore, at face value (i.e., effects concentration versus criterion concentration), the proposal cannot be considered to have only insignificant or discountable effects, as defined in USFWS and NMFS (1998). Therefore, it is necessary to consider whether the "conservative measures" described in the BE would reliably lower the projected cadmium concentrations from their face value concentrations to concentrations that are more likely to be safe for listed salmonids.

7. EFFECTS OF "CONSERVATIVE MEASURES" ON ALLOWABLE INSTREAM CADMIUM CRITERIA

A straight comparison of the acute criterion to documented acute effects at the same concentration indicates adverse effects should be expected. However, USEPA's proposed action (*2010: 67-69*) includes several "conservative measures" which are integral parts to USEPA's implementation of the cadmium water quality criteria. These conservative measures are designed to limit the discharge of pollutants in effluent such that cadmium or other pollutants would seldom be allowed to reach their "face value" criteria concentrations in waters receiving permitted discharges.

Some of these "conservative measures" are more flexible than others and some, such as assumptions of no environmental degradation of pollutants or bioavailability, are less applicable to cadmium than with substances or characteristics such as ammonia, temperature, or oxygen demand. However, based on discussions with USEPA specialists, our own experience, review of relevant provisions of Idaho's rules (*IDEQ 2007*), and review of USEPA's rules (40 CFR 121-122, generally) and guidance (*USEPA 1991*), three flow-related measures in particular are reasonably certain to be implemented consistently and quantifiably. Also, USEPA is the authority that issues National Pollution Discharge Elimination System (NPDES) permits in Idaho and is required to consult with NMFS on permit issuance, which provides additional assurance that the measures will be implemented as proposed. Thus, these three measures were further analyzed to try to quantify their likely conservatism. These were measure #2 to "*Assume the Maximum Permitted Discharge Volume;*" measure #6 to "*Assume Receiving Stream Flows are Very Low;*" and measure #7, to "*Assume that Only a Portion of the Low Stream Flow is Available for Mixing for Controls on Chronic Toxicity*" [mixing zone allowances]. The efficacy of these measures is evaluated below, starting with the mixing zone provisions.

To evaluate both measures quantitatively, the NPDES limits for the Thompson Creek Mine (TCM) were selected as a relevant case study. This facility's permit was chosen because of the facilities with effluent limits or monitoring requirements for cadmium within the action area (*Figure 1)*, the facility seemed to have the necessary information most readily and transparently available to us. This information included:

1. Long-term flow records for the receiving waters were readily available via the internet, with a 37-year period of record (*Figure 7*)[1];

2. A written description of the mixing zone allowances was available online (*Mebane 2000*); and

3. The effluent limitations were available online and the calculations were described in a transparent and reproducible manner (*USEPA 2000*).

The TCM facility has five permitted outfalls that discharge into three very different stream types:

1. Thompson Creek, a small stream with moderately-hard water (5^{th} percentile hardness of 85 to 93 mg/L calcium carbonate) and very little dilution capacity during low flows with a 7Q10 flow of only 2.1 cfs (the 7Q10 is explained later);

2. Squaw Creek, a larger, hardwater stream (5^{th} percentile hardness of 290 mg/L calcium carbonate) with about double the flows of Thompson Creek and a 7Q10 of about 4.6 cfs; and

3. The upper Salmon River, a much larger, softwater stream (5^{th} percentile hardness of 27 mg/L calcium carbonate) with a 7Q10 of about 323 cfs.

The characteristics of these discharges to these three waterbodies are probably reasonably representative examples of the other facilities in *Figure 1* for which less information was readily available.

[1] *http://waterdata.usgs.gov/nwis*

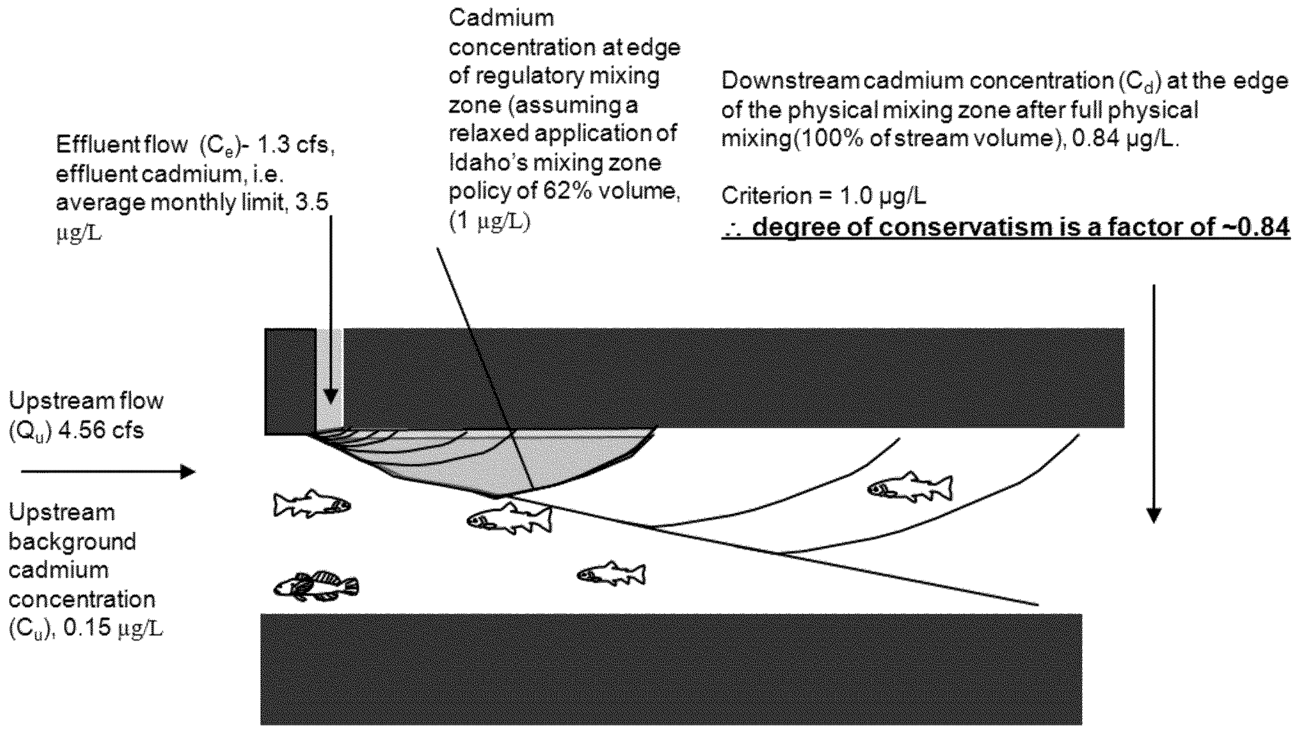
7.1. Efficacy of limiting a portion of the low stream flow for mixing of effluents as a conservative measure (mixing zones)

Measure #7 requires that only a portion of the low receiving waterbody flow is allowed for dilution when calculating the chronic limits. This is done in order to allow space in streams for passage of fish and other mobile aquatic species without having to pass through the mixing zone. This procedure further reduces the volume of the receiving stream which is used for permitting purposes, and therefore provides additional protection to aquatic species from chronic effects. This portion of the flow allowed for dilution is determined by the State of Idaho and is presumed to be 25%, but based upon site-specific analyses of physical, biological, and chemical conditions, the State may authorize other fractions. This discretion to relax or tighten the mixing zone percentage means that the actual conservative factor resulting from this policy may differ from the presumed limitation to 25% of the low stream flow. The State of Idaho is publishing more rigorous guidance on their mixing zone policies and it is now unlikely that mixing zone determinations would be proposed that would permit greater than 25% of receiving water flows to be used to dilute effluents without supporting technical analyses. [2]

For the TCM facility, this discretion was used liberally. For cadmium the with allowable portions of receiving waters allowed for mixing ranging from 5% to 62% of actual stream flow for different streams and flow conditions (*Mebane 2000*). The rationale for setting mixing zone fractions for some substances (Cu, Zn, Se, and Hg) was explained in the mixing zone analysis, but cadmium rationale for the different mixing zone fractions was not explicitly given. The mixing zone stream portions for cadmium are inferred to have resulted from a load allocation split between upstream and downstream outfalls on Thompson Creek, and limiting the travel time for drifting organism through the "acutely toxic" portion of effluent plumes to 1 minute or less, based upon the calculated instream concentrations and modeled time and distance for plume dilutions (*Mebane 2000, table 21*).

Using the calculation methods of USEPA (*2000*), the amounts of conservatism resulting from various mixing zone limitations were evaluated. A pessimistic (i.e., least-conservative) example in which 50% of the portion of the receiving water flow was allowed for mixing of effluents is shown in *Figure 6*. There, the degree of conservatism resulting from the limitation that only a portion of the receiving water stream flow could be used was a factor of 0.84. Other permitted conditions at the TCM facility were calculated as conservative factors ranging from a minimum of 0.22 for the most restrictive 5% mixing zone authorization; to 0.39 for the quasi-default mixing zone of 25% portion of flow; and to 0.84 for the mixing zone allowing 62% of the stream flow to be used.

[2] *http://www.deq.idaho.gov/water/data_reports/surface_water/monitoring/mixing_zones.cfm* accessed 01Oct2010.



$$C_d = \frac{C_u Q_u + C_e Q_e}{Q_e + Q_u} = C_{(downstream)} = \frac{(0.15\ \mu g/L \cdot 4.56\ cfs) + (3.5\ \mu g/L \cdot 0.87\ cfs)}{(0.87+4.56)\ cfs} = 0.84\ \mu g/L$$

Figure 5. Conservatism resulting from a liberal application of Idaho's mixing zone policy which allowed 50% of the streamflow to be used for diluting effluents.

7.2. Efficacy of assuming receiving stream flows are very low as a conservative measure

"Conservative measure" #6 is to "assume that receiving stream flows are very low" is based on USEPA's concept of design flows for effluent discharges. Stream flows are variable and a target of effluent limitations is to approximate provisions in the aquatic life criteria that limit the tolerable frequency of excursions above criteria. In the Idaho water quality standards, for chronic criteria this is defined as the 7-day, once in 10 year low flow or 7Q10 (*USEPA 1991*; *IDEQ 2007*).

In the Thompson Creek example, the concept of a 7Q10 was interpreted by USEPA more liberally than a "7-day, once in 10 year low flow." Rather, "seasonal 7Q10s" were defined where there is a conventional 7Q10, and then there were effluents set for a higher flow tier that occurs during spring snowmelt. While effectively having two 7Q10s for the same time period, the allowable frequency of excursions is higher than if a conventional 7Q10 was used. The higher flow tiers during spring runoff were considered appropriate by USEPA (*2000*) because of the extreme variability in effluent and receiving water flows. To keep comparable levels of protection during the high flow tiers when more effluents could be discharged, USEPA (*2000*) required minimum dilution ratios as part of the permit.

The degree to which the assumption that receiving stream flows are very low acts as a "conservative measure" as stated in USEPA (*2010*) was evaluated by comparing the assumed low flows to the actual flows in Thompson and Squaw Creeks (*Figure 7*). To avoid an optimistic review, water year 2007 was used because it was a year with lower than average flows. Flows in late summer and fall of 2007 (blue line) were considerably lower than the long-term average (brown line). Thompson Creek was in its higher flow tier for about 4 months of the year from March through July. The minimum measured flow in Thompson Creek in 2007 was effectively equal to the 7Q10 flow used in the effluent calculations, 2.1 vs. 2.05 CFS respectively *(Figure 7)*.

To determine to what extent the actual flows provided a "conservative factor" compared to the "low flow 7Q10" of 2.05 CFS and the "high flow 7Q10" of 7 CFS, the low or high "7Q10" was divided by the actual flow for each day during calendar year 2007, and then summary statistics for the year were calculated. The same thing was done with mean daily values for the 37 year period of record (i.e., the mean daily flow for October 1 for all 37 years, October 2 for all 37 years, and so on). These results are summarized in Table 5.

For the four scenarios analyzed, 95% of the time, the low-flow assumption resulted in a "conservative factor" of at least 0.84 (range 0.66-0.84). On the average, the "conservative factors" were about 0.4 (Table 5).

When calculated in this manner, lower proportions are more conservative and a value of one indicates no conservatism in this context. If it can be confusing that "more conservative" values are smaller numbers, it would be equivalent to express the "conservative factors" as reciprocals so that bigger numbers correspond with increasing conservatism. Thus, it would be equivalent to say that 95% of the time, the low-flow assumption resulted in a "conservative factor" of at least 1.2 (range 1.2 to 1.6), and on the average the "conservative factors" were about 2.5.

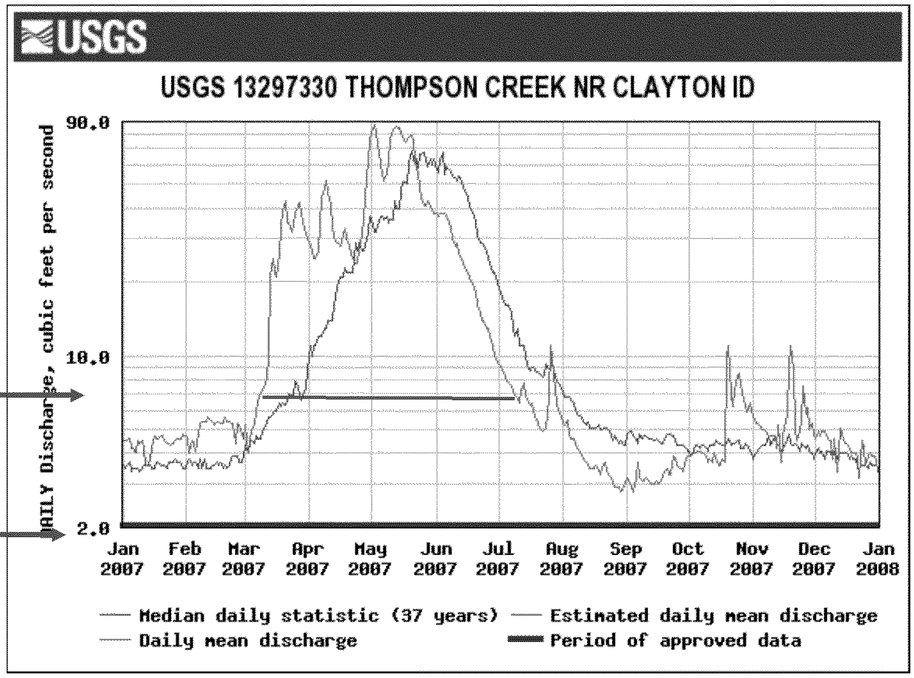
Table 5. "Conservative factors" resulting from assumed low flows in two streams receiving mining effluents. Lower factors are more protective and a factor of 1.0 provides no additional conservatism.

Conservative Factor	Thompson Creek 2007	Squaw Cr 2007	Thompson Cr – 37 year average	Squaw Cr – 37 year average
Median	0.44	0.38	0.43	0.41
Average	0.45	0.40	0.41	0.40
90th percentile	0.70	0.56	0.58	0.50
95th percentile	0.84	0.75	0.76	0.66
Least conservative	1.00	1.00	1.00	0.98

Thus, a moderately pessimistic estimate of how much protection the "conservative factors" actually provided by limiting a portion of the low stream flow allowed for mixing is a factor of 0.84 and for assuming low receiving water flows coincidentally is also about 0.84 (i.e., 95% of the time it is more protective). Since these two measures are combined jointly, their product is 0.70.

Assumed instream flow used to calculate effluent limits to meet criterion during annual high-flow seasons (7 cfs)

Assumed instream flow used to calculate effluent limits to meet criterion during annual stable flow seasons (2.05 cfs)



Assumed instream flow used to calculate effluent limits to meet criterion during annual high-flow seasons (50 cfs)

Assumed instream flow used to calculate effluent limits to meet criterion during annual stable-flow seasons was 4.56 cfs, which is below the chart scale

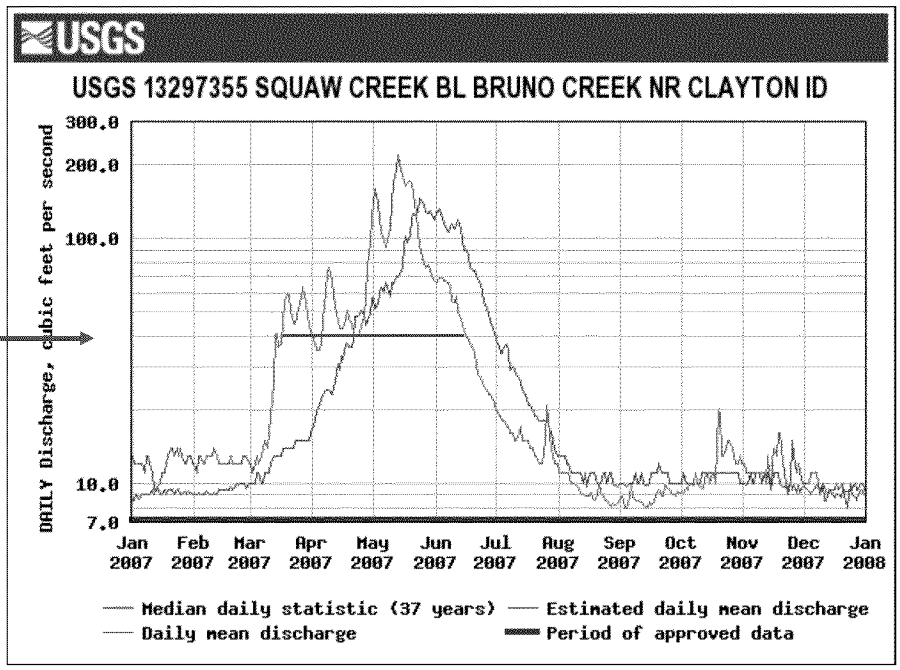


Figure 6. Examples of actual streamflows and streamflows that were assumed to calculate seasonally variable wastewater discharge limits for a facility. Actual flows were estimated to be lower than the assumed flows about 98% of the time (*Mebane 2000*; *USEPA 2000*).

The USEPA's (*2010*) "conservative measure" #2 to "Assume the Maximum Permitted Discharge Volume" is closely related to this analysis of receiving water stream flows. This "conservative measure" is overstated slightly. More accurately, this measure is to assume a higher than average permitted discharge volume, not the absolute maximum. For example, at Thompson Creek outfall #2, the maximum effluent volume contributed 14% of the flow of Thompson Creek. The permit assumed that the effluent would contribute about 8% of the flow which was close to the 99th percentile of flow percentages. The 95th percentile effluent volume contributed about 5% of upstream flows (*Mebane 2000*; *USEPA 2000*). This means that for this outfall, about 95% of the time, effluent volumes were less than or equal to about 5/8 of those permitted, or another "conservative factor" of 0.7. The compounded conservatism of this aspect of effluent limitations would be 0.7 X 0.84 X 0.84 for at least 0.95^2 of the time which equals 0.5 for at least 90% of the time. This can be restated as follows.

The overall conservatism of the three conservative measures evaluated here can be summarized and were estimated as:

Measure A. ("A") Limiting the portion of stream flow allowed for mixing of effluents. The conservatism factor for this measure was estimated at about 0.84 or less (from Figure 5), where the conservatism factor is expressed as a proportion and smaller values are more conservative;

Measure B. ("B") Assuming receiving stream flows are very low. About 95% of the time, the conservatism factor for this measure was also estimated as about 0.84 or less (from Table 5); and

Measure C. ("C") Assuming unusually high permitted discharge volumes. About 95% of the time, the conservatism factor for this measure was estimated at about 0.7 or less (from text following Figure 6).

The overall conservatism of these factors can be estimated as their product, i.e., $A \times B \times C = 0.84 \times 0.84 \times 0.7 \approx 0.5$. The protectiveness of measures B and C vary over time, thus the proportions of time need to be combined. If stream flows and effluent volumes vary independently, then the time proportions should be multiplied together, i.e., $0.95 \times 0.95 = 0.9$. This can be restated that at least 90% of the time, the overall conservatism factor of measures A, B, and C is a factor of 0.5 or less.

If the effluent and receiving water assumptions made for Thompson Creek are further assumed to not be much more stringent or lenient than is typical, then it could be assumed that three of USEPA's "conservative measures" would reduce the allowed cadmium concentrations from point source discharges to about 50% of the criterion values for the great majority of the time. In this case, the allowed instream concentrations would seldom be toxic to sensitive strains or life stages of listed salmonids. If we now re-visit the plot of salmonid cadmium LC50s in comparison to the "face value" cadmium FAV and in comparison to the FAV multiplied by the overall "conservatism factor" of 0.5, we see that the adjusted FAV falls below almost all of the test values (*Figure* 7). This analysis of the effect of USEPA's "conservative measures" was itself fairly conservative in selecting the nearly-least protective aspects of the measures. Thus, it is safe to say that most of the time the overall protective factors would be less than 0.5, i.e, would be more protective (lower is more protective).

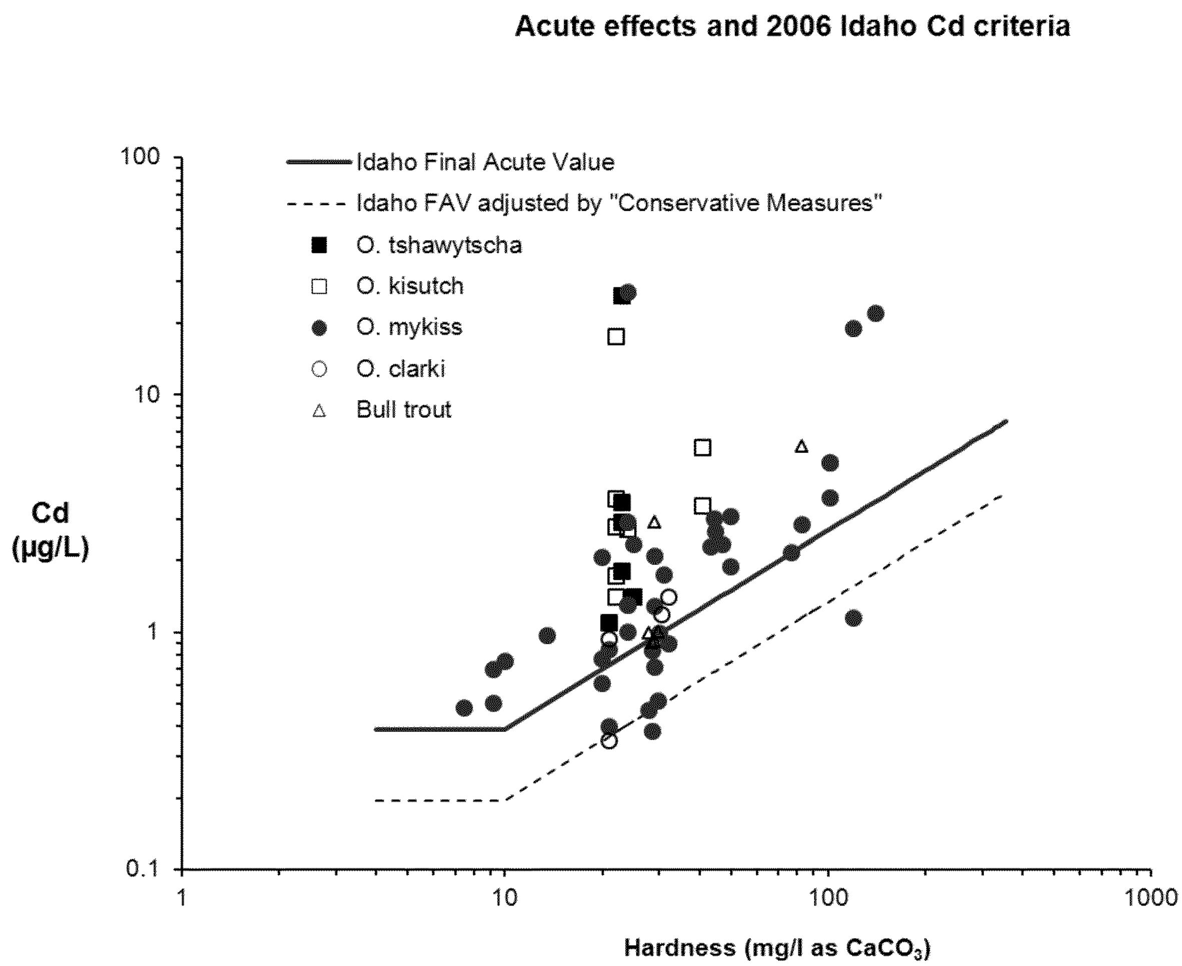


Figure 7. Lethal effects of cadmium to salmonids in comparison to the Final Acute Value (FAV) that was adjusted with an estimated cumulative protective factor of 0.5 resulting from three flow-related "Conservative Measures".

8. CONCLUSION

At face value, the proposed criterion maximum concentration, also referred to as the acute criterion for cadmium is unlikely to adversely affect Snake River spring/summer Chinook salmon, Snake River fall Chinook salmon, or Snake River sockeye salmon. This is the case because all reports reviewed of concentrations causing acute effects to Chinook salmon or to sockeye salmon were higher than the comparable criteria statistics. However, a substantial fraction of the available acute data most relevant to Snake River steelhead do indicate adverse effects. Therefore, estimates of the efficacy of three of USEPA's proposed "conservative measures" which related to effluent and receiving water flow volume assumptions were made. The estimates were that for about 90% or more of the time, the compounded conservatism resulting from three flow-related assumptions was about a factor of 0.5 or less (i.e., would be about twice as protective as the "face value" criteria concentrations). As implemented with conservative measures, the resulting cadmium concentrations would be lower than the great majority of data reviewed on adverse effects of cadmium. This would likely result in only insignificant effects to Snake River Basin steelhead.

For these reasons, the cadmium criteria that are proposed for approval for Idaho would be likely to only have insignificant effects on listed Snake River anadromous salmonids or their designated critical habitats.

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